

**Studies for the Loss of Atomic  
and Molecular Species from Io**

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13. ABSTRACT (Maximum 200 words)  Updated neutral emission rates for electron impact excitation of atomic oxygen and sulfur based upon the Collisional Radiative Equilibrium (COREQ) model have been incorporated in the neutral cloud models. An empirical model for the Io plasma torus wake has also been added in the neutral cloud model to describe important enhancements in the neutral emission rates and lifetime rates in this spatial region. New insights into Io's atmosphere and its interaction with the plasma torus are discussed. These insights are based upon an initial comparison of simultaneous Io observations on October 14, 1997, for [OI] 6300Å emissions acquired by groundbased facilities and several ultraviolet emissions acquired by HST/STIS in the form of high-spatial-resolution images for atomic oxygen and sulfur.			
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## I. Introduction

The general objective of this project is to advance our theoretical understanding of Io's atmosphere by studying how various atomic and molecular species are lost from this atmosphere and are distributed near the satellite and in the circumplanetary environment of Jupiter. The project is divided into well-defined studies described for the likely dominant atmospheric gases involving species of the SO<sub>2</sub> family (SO<sub>2</sub>, SO, O<sub>2</sub>, O, S) and for the trace atmospheric gas atomic sodium. The relative abundance of the members of the SO<sub>2</sub> family and Na (and its parent NaX) at the satellite exobase and their relative spatial densities beyond in the extended corona of Io are not well known but will depend upon a number of factors including the upward transport rate of gases from below, the velocity distribution and corresponding escape rate of gases at the exobase, and the operative magnetospheric/solar-photon driven chemistry for the different gases. This question of relative abundance will be studied in this project.

In order to address this question, we will undertake theoretical modeling studies for the distribution and time variability of these exospheric gases in Io's corona/extended clouds and will evaluate the importance of various physical processes that shape their relative abundances and escape rates. Our primary objective will be to study near-Io emission observations for O, S, and Na, most of which have already been acquired and some of which are scheduled to be acquired in 1996-1997 as part of the larger coordinated International Jupiter Watch Observational Campaign to support the Galileo mission. A secondary objective will be to continue the study of various larger-spatial-scale groundbased sodium and spacecraft (Voyager and Galileo) SO<sub>2</sub><sup>+</sup> observations in order to address related issues and to lay the groundwork for larger-spatial-scale O and S observations likely to be obtained in the near future. The proposed studies are of scientific importance in understanding (1) the atmosphere of the satellite, (2) the interactions of the magnetospheric plasma and the atmosphere, (3) the nature and composition of the heavy ion sources for the plasma torus, (4) the impact of these gases on the larger magnetosphere, and (5) the spatial distribution of these gases in the magnetosphere and beyond in the larger solar wind environment.

Near-Io observations for this project will be made available in four collaborative efforts established with

- (1) F. Scherb of the University of Wisconsin-Madison who from groundbased facilities in 1990-1996 very successfully obtained synoptic observations of [O I] 6300 Å emission near Io and in 1996-1998 will continue these synoptic observations, search for [O I] 5577 Å emission, and add a new Fabry-Perot program element using the new WIYN telescope

at Kitt Peak to obtain very-high spatial resolution images near Io in the [O I] 6300 Å and Na 5890 Å emission lines,

(2) G. E. Ballester of the University of Michigan who with HST has acquired cycle IV and will be acquiring cycle V observations for O and S near Io in various UV emission lines,

(3) L. M. Trafton of the University of Texas who has obtained in 1984-1989, and in his ongoing program in 1995 and 1996, groundbased observations for the north-south spatial distribution and spectral line shape of sodium (5890 Å, 5896 Å) emissions near Io, and

(4) N. M. Schneider of the University of Colorado-Boulder who obtained in 1987 from groundbased facilities an extensive set of observations for the east-west spatial distribution and spectral line shape of sodium emissions near Io, which exactly overlap the October 1987 observations of Trafton.

These near-Io emissions exhibit time variability with Io System III longitude and Io east-west location. The general three year plan of research for these studies is outlined in Table 1.

## **II. Summary of Work Performed in the Second Bi-Monthly Period of Year Two**

Work accomplished in second bi-monthly period of the second project year includes (1) neutral cloud model update for the electron-impact neutral emission rates, (2) the addition in the neutral cloud model of a simple empirical description for the Io plasma wake located downstream of the satellite, and (3) a trip to the University of Wisconsin-Madison to review Io related science with our collaborator Dr. F. Scherb.

### **2.1 Neutral Cloud Model Update for the Electron-Impact Neutral Emission Rates**

The new neutral emission rates for atomic oxygen and sulfur resulting from electron impact excitation as calculated using the Collisional Radiative Equilibrium (COREQ) model and discussed in the previous progress report have been incorporated in the neutral cloud models. The updated emission rates cover a large range for the electron temperature and density suitable for conditions both in the plasma torus and in the plasma wake downstream of Io. Preliminary model calculations for the [O I] 6300 Å emission observations near Io discussed in the previous progress report are now being repeated with the new excitation rates and are anticipated to yield new atomic oxygen source rates that are approximately 20% larger than those acquired earlier.

## 2.2 Empirical Model for the Io Plasma Wake

A simple empirical description of the Io plasma wake located downstream of the satellite has been added in the neutral cloud model. The model is based upon the general behavior of the plasma in the wake as determined by *in situ* measurements of particle instruments on the Galileo spacecraft in its December 7, 1995 encounter with Io. For these measurements along the spacecraft trajectory with a closest approach to the satellite surface of  $\sim 900$  km, the plasma density was enhanced at the center of the wake by a factor of  $\sim 10$  over the background whereas the ion temperature had a minimum at the center of the wake with a peak on either side that then relaxed to lower background values at larger distances. The plasma description in the wake is important to describe for neutrals the effects of wake-enhanced electron-impact excitation rates and lifetime rates in this spatial region. A critical parameter in the wake region that is not yet available from the Galileo measurements along the spacecraft trajectory is the electron temperature. This will hopefully be forthcoming in the near future. In the meanwhile, modeling of the [O I] 6300 Å emission images that were acquired by HST measurements (Trauger et al. 1997) and discussed in the last bi-annual report of the first project year will provide, when available, one avenue to probe the electron temperature in the Io wake region.

## 2.3 Collaborative Visit to The University of Wisconsin-Madison

During December 10-14, 1997, the Principal Investigator visited the University of Wisconsin-Madison. The purpose of this visit was to discuss Io related project science with the collaborator Dr. F. Scherb regarding (1) the groundbased [O I] 6300 Å observations of Io as summarized in the previous progress report and (2) the relationship of these [O I] 6300 Å observations to new spectacular high-spatial-resolution images of Io in different ultraviolet emission lines of atomic oxygen and sulfur that were very recently acquired by Dr. F. Roesler (University of Wisconsin-Madison) using the new HST Space Telescope Imaging Spectrograph (STIS).

For the groundbased [O I] 6300 Å observations, the massive effort of data reduction and extraction of the absolute emission line brightness is progressing well. Examples of time variability of the absolute 6300 Å brightness on different observing nights in 1997 were examined. Of particular interest were a sequence of [O I] 6300 Å observations on October 14, 1997 that were acquired simultaneously with HST/STIS high-spatial-resolution images of Io. These HST/STIS images were obtained in several ultraviolet emission lines for atomic oxygen and sulfur as well as the surprise discovery of hydrogen Lyman- $\alpha$  emission present only at the two polar regions of Io. These observations and their very preliminary analysis were recently presented at the January meeting of the American Astronomical Society (Roesler et al. 1998).

The HST/STIS high-spatial-resolution images were acquired when the satellite was near western elongation so that Io obscured the emission coming from the satellite wake region. For this viewing geometry, the ultraviolet emissions for atomic oxygen and sulfur were observed to be concentrated in spots near the satellite equator. These equatorial spots extend well above the satellite limb and are roughly aligned with the magnetic equipotential line through Io. In addition, the ultraviolet emissions for atomic oxygen and sulfur were observed to extend diffusely around the entire limb of Io with an enhancement on the side of Io toward the centrifugal equator of the plasma torus. Of particular importance is the temporal variability of the ultraviolet O and S line intensities for these equatorial spots which is strongly correlated with the simultaneous groundbased observations of the [O I] 6300 Å emission intensity. This correlation is extremely important since it tells us (1) that both the visible and ultraviolet emission lines for oxygen (and sulfur) are experiencing globally a similar time-variable excitation phenomena, and (2) that the large seven-year data base for the visible [O I] 6300 Å emission intensity can now be studied to probe the nature of the excitation phenomena for both short term (~1 hour) variability, time-average System III longitude variability, and local-time variability.

## REFERENCES

- Roesler, F. L., F. Scherb, R. C. Woodward, H. W. Moo, R. J. Oliverson, W. H. Smyth, D. T. Hall, and M. McGrath, STIS Low Spectral Resolution FUV Images of Io, 191st AAS Meeting in Washington, D. C., January 6-10, 1998.
- Trauger, J. T., K. F. Stapelfeldt, G. E. Ballester, J. T. Clarke, and WFPC2 Science Team (1997) HST Observations of [O I] Emission from Io in Eclipse, BAAS 29 1002.

Table 1

Three Year Plan of Research for Studies for the Loss of Atomic and Molecular Species from Io

Subject	Year 1	Year 2	Year 3
Studies for the SO <sub>2</sub> Family	Analyze HST (cycle IV) UV data for O and S and available [O I] 6300 Å synoptic data for O using the O, S, SO and SO <sub>2</sub> cloud models; improve model execution time, update chemistry and refine the model description of the plasma torus.	Analyze the HST (cycle V) UV data for O and S; initiate analysis of Fabry-Perot image data for [O I] 6300 Å and [O I] 5577 Å (if relevant); re-analyze Voyager SO <sub>2</sub> <sup>+</sup> data; determine sources rates and constraints on O, S, SO and SO <sub>2</sub> for the individual studies.	Complete analysis of UV and optical data; undertake the comparative and collective assessment of the individual studies for O, S, Na and SO <sub>2</sub> <sup>+</sup> to probe the nature of the atomic and molecular species in Io's atmosphere and their implications for the Jupiter system.
Studies for Sodium	Continue the analysis of the 1987 east-west emission data set; initiate analysis of the same-date 1987 north-south emission data; refine model description of the plasma torus; re-evaluate the Na source at Io for the directional feature.	Complete analysis of the 1987 east-west emission data set; undertake analysis of other select years of the north-south emission data set; determine the nature and variability of the Na source conditions and their dependence on east-west and System III effects; analyze Fabry-Perot images for sodium and compare with [O I] 6300 Å images; assess the importance of the electron impact excitation and/or nonuniform gas distributions as a cause for asymmetric brightness distributions about Io.	